(2)

AL-TP-1991-0027

AD-A239 307

ARMSTRONG LABORATORY

MANPOWER IMPACTS OF JOB AIDING TECHNOLOGY

Edward Boyle

HUMAN RESOURCES DIRECTORATE
LOGISTICS RESEARCH DIVISION
Wright-Patterson Air Force Base, OH 45433-6503

John R. Plassenthal

Systems Research Laboratories, Incorporated
2800 Indian Ripple Road
Dayton, OH 45440-3696

William Weaver, Capt, USAF

HUMAN RESOURCES DIRECTORATE
MANPOWER AND PERSONNEL DIVISION
Brooks Air Force Base, TX 78235-5000

June 1991

Interim Technical Paper for Period September 1990 – May 1991

Approved for public release; distribution is unlimited.

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

NOTICES

This technical paper is published as received and has not been edited by the technical editing staff of the Armstrong Laboratory.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Public Affairs Office has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

EDWARD BOYLE
Contract Monitor

BERTRAM W. CREAM, Technical Director
Logistics Research Division

JAMES C. CLARK, Colonel, USAF
Chief, Logistics Research Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1991	Interim Tech Paper - September 1990 - May 1991

4. TITLE AND SUBTITLE
Manpower Impacts of Job Aiding Technology

5. FUNDING NUMBERS
PE - 62205F
PR - 1710
TA - 00
WU - 04

6. AUTHOR(S)
Edward Boyle
William Weaver
John R. Plassenthal

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Logistics Research Division
Wright-Patterson Air Force Base, OH 45433-6503

8. PERFORMING ORGANIZATION REPORT NUMBER
AL-TP-1991-0027

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

A series of simulations using the Logistics Composite Model (LCOM) identified manpower benefits that could be attributed to the Integrated Maintenance Information System (IMIS). These simulations measured manpower levels under different assumptions about equipment reliability, sortie rate, and maintenance troubleshooting times. Sixteen LCOM studies were performed. Manpower was found to be sensitive to variation in each factor. The LCOM data showed that if the maintenance job aiding benefits of IMIS led to significant reduction in task performance time, then the potential saving in manpower and cost would be substantial.

14. SUBJECT TERMS
Integrated Maintenance Information System (IMIS)
manpower
job performance aids
logistics composite model

15. NUMBER OF PAGES
36

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

This paper describes how the Air Force Logistics Composite Model (LCOM) was used to estimate the manpower impacts of advanced technology job aids for maintenance. The study arose from a requirement to quantify the benefits and costs of implementing the Integrated Maintenance Information System (IMIS). The work was performed under Work Unit 1710-00-04 entitled "Maintenance Personnel Requirements for Dispersed Combat Operations." The authors thank Mr. Bertram Cream and Captain Rick Berry for aid and comfort.

SUMMARY

The Logistics Composite Model (LCOM) was used to estimate maintenance manpower efficiencies that could be attributed to the Integrated Maintenance Information System (IMIS). Simulations measured manpower requirements under varying equipment reliability levels, sortie rates, and troubleshooting times. Sixteen LCOM studies were performed. Manpower was found to be sensitive to variation in each factor. The LCOM data show that if the maintenance job aiding benefits of IMIS lead to a significant reduction in task troubleshooting time, the potential saving in maintenance manpower - and cost - could be substantial.

MANPOWER IMPACTS OF JOB AIDING TECHNOLOGY

I. INTRODUCTION

New computer technologies like the Integrated Maintenance Information System (IMIS) and new organizational concepts like Rivet Workforce are intended to improve the quality of Air Force maintenance Advanced job aids for technicians should reduce maintenance errors repair times. Greater flexibility in worker utilization should lead to greater combat resiliency. These and similar maintenance innovations are bound to become more valuable as the Air Force becomes smaller. Does a reduction in manpower authorizations necessarily diminish unit productivity? How can we gauge the impacts of technologies like IMIS on maintenance manpower needs? These are complex questions without simple answers. But they are increasingly relevant. The purpose of this probe study was to illustrate the potential effects of new technology for maintenance aiding on worker productivity and organizational effectiveness. Specifically, the purpose was to estimate the effects of successful introduction of IMIS on unit maintenance manpower requirements.

What is IMIS?

IMIS is a family of technologies intended to improve the utility of maintenance information for the technician, and thereby to improve maintenance quality. Figure 1 shows the general IMIS concepts The unifying goal of IMIS is to integrate the disparate information sources used in Air Force maintenance work into a single, coherent, hardware/software system tailored to the technician's needs.

IMIS technology is divided into three broad areas. First, the technician is to be provided with a very small but powerful portable computer. This computer will interface with both on-aircraft diagnostic data systems and ground-based maintenance information systems such as the Core Automated Maintenance System (CAMS) and the Joint Uniform Services Technical Information System (JUSTIS). It will be ruggedized and battery-powered. A high-resolution screen will display complex maintenance instructions using both graphics and text. The computer's software will support interactive troubleshooting and will contain artificial intelligence-based diagnostic aiding for complex fault isolation. In this latter aspect the IMIS portable computer can be thought of as an advanced technology job performance aid (JPA).

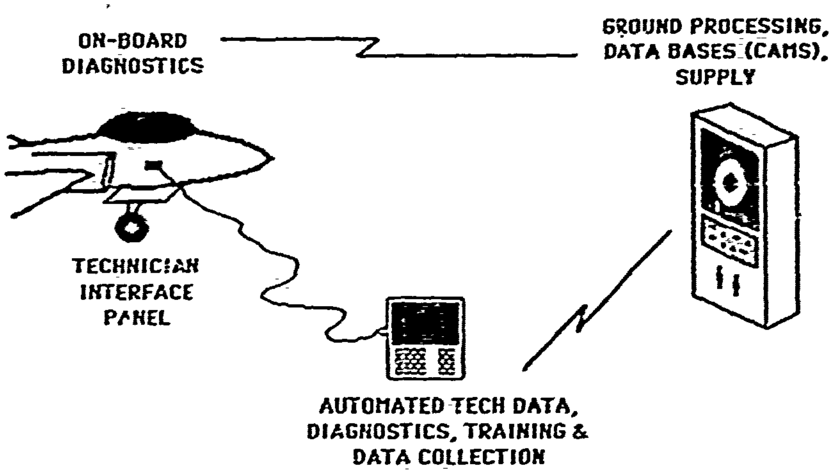

Figure 1. IMIS Concepts

Second, a maintenance panel on the outside of the aircraft will provide an interface to on-aircraft diagnostic systems. The panel will be used to retrieve data on configuration and subsystem status, interrogate built-in test, and upload/download mission software. The panel may also be used with the portable computer for diagnostic aiding. The location of the panel will allow for maintenance diagnostic monitoring and troubleshcoting without entering the cockpit.

Third, the portable computer will interface with a desktop workstation which will have a full keyboard and an interface computer. The technician will communicate through a workstation interface with CAMS, JUSTIS, and other maintenance management information systems. The IMIS workstation, used away from the aircraft, will also support computer-aided training for maintenance technicians through specialized software modules.

IMIS Benefits

Maintenance quality is expected to improve in several ways with IMIS technology. Maintenance job instructions -- called Technical Orders, or TOs -- will become more convenient to use and easier to keep up-to-date. Since the information they contain will be more dependable, technicians will use the TOs more effectively. The coupling of computer-based troubleshooting aids with better on-board fault diagnostics should greatly reduce the incidence of "no defect" maintenance. Improvements in maintenance accuracy and efficiency will be reflected in decreased repair time and a reduced demand for spare parts. In sum, IMIS should help to increase maintenance productivity and lower logistics support costs.

But this is not all. IMIS is expected to become an enabling technology for other maintenance improvements. Some believe that the advanced job aiding features of IMIS will permit job enlargement for maintenance people. Many tasks, particularly troubleshooting tasks, should become easier to learn and to perform. In the future, an IMIS-supported maintenance environment should allow a versatile few to accomplish the same work now done by the specialized many. A leaner maintenance workforce will contribute to the combat mobility, flexibility and sustainability the Air Force increasingly requires of its fighting units. At the same time, job enlargement aided by IMIS technology may also lead to lower peacetime manpower costs.

A question naturally arises. Can these IMIS benefits be quantified? One method is to use a simulation of the maintenance environment, comparing maintenance as it is now with maintenance as it is expected to be once IMIS is successfully implemented. If IMIS makes maintenance more efficient, we should be able to measure this effect in reduced repair times for individual maintenance tasks. These individual task time reductions, when aggregated over an entire maintenance unit, should lower manhours overall. This, in turn, should lead to a lowered manpower requirement. Such was the logic implemented in this study. For a given workload and performance requirement, we can quantify one benefit of IMIS in the lowered demand for maintenance manpower. Since manpower can be readily quantified and costed, we can use this as one indicator of the benefit from IMIS technology.

II. METHOD

The Logistics Composite Model (Drake & Wieland, 1982) was used to estimate the potential manpower benefits of IMIS implementation in the maintenance environment. LCOM is an approved and well established method for deriving maintenance manpower requirements in the Air Force. We exercised the LCOM model to simulate the effects of one of the most important benefits expected from IMIS. the reduction in troubleshooting repair times and the consequent lowering of maintenance manhours.

Other potential IMIS benefits, such as the effects of IMIS-supported maintenance on spare parts consumption, can also be modeled with LCOM, but were not included in this analysis. We chose instead to model the manpower effects in some detail by looking at the interactions of repair time variations in conjunction with improvements in equipment reliability and variations in sortie generation demand.

An experimental design for the LCOM simulations is shown in Table 1. Flying objectives of 1.5 and 3.0 sorties per aircraft per day were chosen. We simulated the manpower effects ("M" in

Table 1) of three scenarios for troubleshooting task time reduction with IMIS: 30, 60, and 100 percent, and compared each with baseline troubleshooting times we found in the LCOM data base. The 100 percent reduction essentially eliminated troubleshooting time entirely, and hence provides an upper bound. We implemented these task time changes by adjusting each troubleshooting task in the LCOM data base. These reductions simulate the effects of more efficient and more accurate diagnostic capability on overall task performance time owing to IMIS technology.

The values for troubleshooting time reductions were chosen arbitrarily. Literature searches to estimate plausible ranges for troubleshooting time reductions with job aids were generally unavailing. Nugent, Sander, Johnson, & Smillie (1987) present relevant but limited troubleshooting performance data with IMIS-like job aids. Nelson, Gay, and Roll (1974) summarize the literature on JPA impacts on maintenance productivity, but present no empirical data that could be used to benchmark the LCOM task times. Hence, our approach was really a sensitivity analysis only. It is like asking: How much must task performance times decrease before LCOM shows a manpower benefit from IMIS?

To examine the effects of improved equipment reliability, we adjusted the LCOM failure mechanisms to reflect the findings of the "High Reliability" Fighter Study (McDonnell Douglas, 1987). That study, sponsored by Aeronautical Systems Division (ASD), produced a baseline comparison system and projected subsystem reliability improvements for a notional next-generation fighter. Reliability here means how often an item needs repair.

<u>Table 1</u>. IMIS Cases Studied With LCOM.

Equipment Failures	Sortie Rate	Task Troubleshooting Time: Baseline	-30%	-60%	-100%
Baseline	Low (1.5)	M	M	M	M
	High (3.0)	M	M	M	M
Improved Reliability	Low (1.5)	M	M	M	M
	High (3.0)	M	M	M	M

We limited manpower studies to on-equipment (or flightline) maintenance specialties. IMIS is expected to impact these work centers most, and since we did not deal with spare parts optimization, manpower for off equipment (or shop) work centers could not be constrained properly. (See the Appendix for details on LCOM manpower constraining.)

In all cases, we modeled a 24 aircraft unit flying a 30-day combat scenario from a single base. Sortie rates were arbitrarily chosen to simulate high tempo operations at two levels. The aircraft were fighters in air to air missions. There was no attrition, no battle damage, and round-the-clock flying. The scenarios were modeled using ASD's LCOM Version 88.B running under VAX/VMS.

We manipulated only the troubleshooting times in the LCOM data base. We did not adjust active repair or repair check out times. The troubleshooting portion of many maintenance tasks is substantial, but it is only part of a complete task as LCOM typically models it. Overall task times were reduced, but we used a conservative approach by lowering only the time for troubleshooting.

LCOM Data Base

We created an LCOM maintenance task data base for a notional new fighter using a method described by Tetmeyer (1974). This method, called Comparability Analysis, is used to identify comparable subsystems from existing equipment when forecasting maintenance requirements for new systems not yet built. Comparability Analysis is now commonly used to predict the logistics characteristics of new systems -- essentially reliability and maintainability values -- from the characteristics of existing systems. The results of this effort are shown in Table 2 at the "two-digit" equipment work unit code level.

As shown, we created a baseline equipment configuration for a notional new Air Force fighter consisting of subsystems from existing fighters. We then located and integrated existing LCOM data sets, including one for the Navy F/A-18, describing the maintenance requirements for these subsystems. We then had the nucleus of a new LCOM data base representing our notional new fighter. Projected improvements in equipment reliability, measured as mean sorties between failure, were drawn from the "High Reliability Fighter" study (McDonnell Douglas, 1987). These values were used to adjust the LCOM failure mechanisms which control the volume of maintenance repair work in the simulation.

Maintenance Air Force Specialty (AFS) Groups. AFS Groups for on-equipment (flightline) maintenance were defined as shown in Table 3. We used AFS designations prevailing before the Rivet Workforce change in AFS policy as they would have applied to a future Air Force fighter.

Table 2. LCOM Baseline Comparison Subsystems.

Work Unit Code	Subsystem	Work Unit Code	Subsystem
11 Airframe	F16,F15,F/A-18	49 Misc.Utilities	F/A-18
12 Cockpit	F16, F15, F/A-18	OBIGGS[2]	F/A-18
13 Landing Gear	F15	51 Instruments	F/A-18
14 Flight Controls	F16,F15,F/A-18	62 VHF[3]	F/A-18
24 Auxiliary Power	F/A-18	63 UHF[4]	F/A-18
27 Propulsion	F15	64 Interphone	F/A-18
29 Power Plant	F/A-18	65 IFF[5]	F/A-18
41 Environmental	F16	66 Radio Beacon	F/A-18
42 Electrical	F15	67 Comm/Nav/IFF[6]	F/A-18
44 Lighting	F15	71 Radio Nav.	F/A-18
45 Hydraulics	F/A-18	72 Radar/Bomb Nav.	F/A-18
46 Fuel	F15	74 Fire Control	F/18,F15
47 Oxygen (OBOGS)	AV-8A[1]	75 Weapons	F/A-18
		76 ECM[7]	F/A-18

1On Board Oxygen Generating System
2On Board Inert Gas Generating System
3Very High Frequency (Radio)
4Ultra High Frequency (Radio)
5Identification Friend or Foe
6Communication/Navigation/Identification Friend/Foe
7Electronic Counter Measures

LCOM Manpower Modeling. LCOM is a large-scale Monte Carlo simulation of a maintenance organization. The essentials of this complex model are discussed in the Appendix. The simulation uses a description of the maintenance environment in the form of task networks to help an analyst determine an economic mix of maintenance resources to support a given operational scenario. In LCOM simulation, the basic idea is to adjust base-level logistics resource levels, including the manpower resource, until the desired performance, usually a target sortie rate, is just achieved. In this way, the level of the manpower resource can be tied to a level of performance and the interactive effects of manpower with other logistics factors can be estimated.

We derived AFS-by-shift manning levels for each case separately. This was done by adjusting AFS manning levels up or down over successive simulation trials until the desired sortie rate was just achieved. In converting shift manpower to total manpower, we used a wartime manpower availability factor of 244.8 hours per person per month.

Table 3. AFS Groups for LCOM Simulation.

AFS	Function	AFS	Function
326X6	Fire Control	423X2	Egress
326X7	Instruments		
326X8	Comm/Nav/ECM	427X2	Sheet Metal
		427X5	Inspection
431X1	Airplane General		
423X4	Pneudraulics	423X3	Fuels
426X2	Engine		
		462X0	Munitions
423X0	Electrical	461X0	Armament
423X1	Environmental		

III. RESULTS

Table 4 shows the overall results of these LCOM simulations. Both LCOM daily shift manning (Shift) and total authorizations (Total) are shown. In general, as troubleshooting times decline, so does the manpower requirement. For example, looking at the second row in the table, the manpower needed under baseline conditions with a 1.5 sortie workload is 164 people. This manpower requirement declines slightly when troubleshooting times are reduced by 30 percent across the board, and substantially when troubleshooting times are reduced by 60 percent across the board. If troubleshooting times across all tasks for all AFSs were effectively nulled, only 118 people would be required. Other rows in Table 4 can be interpreted in a similar fashion.

As expected, the lowest manpower solutions are obtained when sortie demand is relatively low and equipment reliability is high. Figure 2 shows that the sensitivity of manpower to troubleshooting times is greatest when sortie requirements are very high. The two top curves show that manpower requirements drop off sharply when these times are reduced only modestly (30%). In contrast, when sortie generation requirements are relatively low, troubleshooting times must be cut by 60 percent before a noticeable manpower decline is observed. All four curves imply that eliminating troubleshooting completely would not decrease manpower requirements much more than a 60 percent reduction in troubleshooting time. Eliminating troubleshooting time entirely does not seem possible, but reducing it by 60 percent does seem possible, and it would give about the same overall benefit. As expected, lowering the volume of required maintenance work by improving equipment reliability lowers required maintenance manpower, regardless of other factors. All of these findings make intuitive sense.

Table 4. IMIS Effects on Manpower Levels.

Equipment Failures	Sortie Rate		Task Troubleshooting Time Baseline	-30%	-60%	-100%
Baseline	Low (1.5)	Shift	112	110	94	80
		Total	**164**	161	138	118
	High (3.0)	Shift	169	150	142	134
		Total	248	220	209	197
Improved Reliability	Low (1.5)	Shift	90	90	90	84
		Total	132	132	132	123
	High (3.0)	Shift	127	116	106	104
		Total	187	171	156	153

Notes: 1. Manning is for on-equipment maintenance of a 24-aircraft unit.
2. Computational formula for total manpower is: (Shift) x (30 days) x (12 hours) / (244.8 hours).

Reckoning Manpower Costs. If IMIS technology successfully implemented lowers manpower requirements for a given level of sortie performance, the next question must be: How much could be saved if these manpower economies were actually realized? In other words, what is the manpower cost avoidance attributable to this IMIS benefit?

To estimate the value of this benefit, we obtained manpower cost factors from Air Force Regulation 173-13 and applied them to our LCOM-derived total manpower requirements according to the rules stated therein. We simply multiplied the manpower requirement by the annual cost of a manpower space for each of the sixteen cases we modeled. We took no account of recruiting, training, or other indirect costs that are also associated with these direct manpower costs, though these too would be affected by altered field manpower requirements. The results are shown in Table 5.

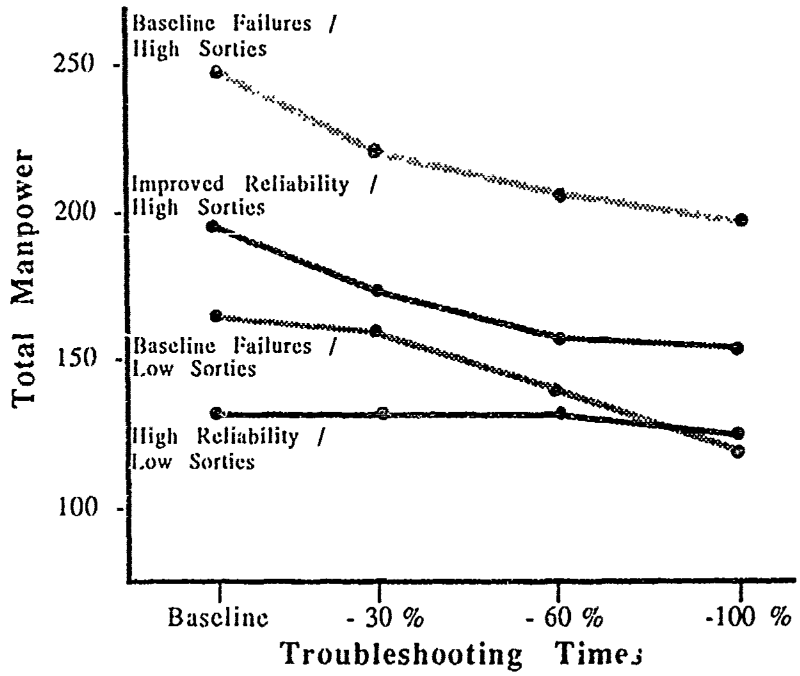

Figure 2. IMIS Effects on Manpower Levels.

Table 5. Annual Manpower Costs.

Failures	Sortie	Manpower	Equipment	Task Troubleshooting		Time
	Rate		Baseline	-30%	-60%	-100%
Baseline	Low	Total	164	161	138	118
		Cost	4.459	4.377	3.752	3.208
	High	Total	248	220	209	197
		Cost	6.743	5.982	5.683	5.366
Improved Reliability	Low	Total	132	132	132	123
		Cost	3.589	3.589	3.589	3.344
	High	Total	187	171	156	153
		Cost	5.085	4.649	4.242	4.160

Notes: 1. Manpower costs are in millions of dollars.
2. The annual average cost per enlisted person is $27,191.00
(See Air Force Regulation 173-13)

If we assumed that the most likely overall effect of IMIS's job aiding benefit is a 60 percent average reduction in maintenance troubleshooting times, and also assumed a workload factor equivalent to a 1.5 average daily sortie rate, the applicable manpower cost would be $3,752,000 annually. (Refer to 3.752 in Table 5.) This could be subtracted from $4,459,000 (the applicable baseline case) to yield $707,000. This amount could be called the manpower cost avoided by IMIS for one 24-aircraft unit for one year. Extrapolating, if we had ten IMIS-supported fighter wings of three 24-aircraft squadrons each, we would avoid $21,210,000 in manpower costs in one year (i.e., $707,000 x 3 x 10) by implementing IMIS. Other entries in Table 5 can be converted to manpower costs in the same way.

IV. DISCUSSION

These LCOM studies show a strong and consistent relationship between IMIS technology, manpower, and maintenance system performance. We observed substantial manpower benefits from IMIS by altering maintenance troubleshooting times. We can readily convert manpower authorizations to manpower costs using standard cost data to show potential cost avoidances reaching into the millions annually from this single improvement in maintenance quality. For a given level of sortie demand, reducing maintenance manhours by reducing troubleshooting times leads to lower manpower costs. In sum, we have demonstrated the manpower effects that some have projected for an IMIS-supported maintenance world. Until now, there has been little attempt to quantify these potential manpower benefits.

It should be noted that other IMIS impacts are not captured here. To obtain a broader view of IMIS benefits (and costs), the economic effects of reduced maintenance errors on spare parts demand would have to be considered. Better maintenance performance and improved equipment reliability would reduce not only manpower requirements, but spare parts stockage requirements as well. We did not model a reduction in "Cannot Duplicate" maintenance actions on the flightline or "Retest OK" events in the shop, two commonly used indicators of troubleshooting quality (Binkin, 1986). We merely reduced the time needed to make a diagnostic decision without examining the quality of the decision. Even so, the results obtained using only one maintenance factor strongly suggest that further study of manpower and spare parts costs associated with IMIS-supported maintenance would also be very worthwhile. A detailed IMIS cost analysis "shell" developed by Coogan, Brandt, and Jernigan (1984) would be useful for this more detailed assessment.

LCOM does not capture all of the potential manpower impacts expected from IMIS. Several work centers not included in LCOM manpower simulations will be altered in an IMIS-supported maintenance environment. For instance, the TO maintenance function at unit level may well have different manning requirements in addition to different personnel skills when the work shifts from management of paper TO's to digital media. And maintenance of the IMIS system itself would have to be considered in the overall unit manpower requirement. These and other manpower impacts would have to be considered if the fuller cost/benefit analysis of IMIS is to be undertaken.

In addition to reducing maintenance times, IMIS can be expected to help reduce the number of occupational specialties required for aircraft maintenance. The Rivet Workforce initiative has made maintenance job enlargement an important consideration in manpower planning for current and future Air Force system support. We have begun another LCOM study on Rivet Workforce AFS policy with the same data base used here.

Since this was only an exploratory analysis, we did not attempt to establish statistical confidence limits for any of the LCOM studies reported here, nor did we examine the potential impacts of IMIS beyond flightline manpower. We have only established that manpower requirements derived with LCOM are indeed sensitive to conservative assumptions about the effects of advanced job aiding technology. Since the validity of these assumptions has not been verified, the validity of the LCOM findings is uncertain. All the usual cautions about overgeneralizing results from a single study certainly apply here.

Even so, the evidence we do have indicates that more detailed and more rigorous research is warranted. In addition to -- or instead of -- more comprehensive and rigorous LCOM modeling, this research might stress behavioral measurement of job aiding effects in realistic field conditions. Obtaining such real world performance data will be difficult and costly. But without them, follow-on research will be limited to more elegant and more extensive simulations.

V. REFERENCES

Bell, C., & Stucker, J. (1971, May). A technique for determining maintenance manpower requirements for aircraft units. (R-770-PR, AD 733561). Santa Monica, CA: The Rand Corporation.

Binkin, M. (1986). Military technology and defense manpower. Washington, DC: The Brookings Institution.

Boyle, E. (1990, April). SUMMA summary. (AFHRL-TP-90-82, AD-A229 836). Wright-Patterson Air Force Base, OH: Logistics and Human Factors Division, Air Force Human Resources Laboratory.

Coogan, C., Brandt, C., & Jernigan, J. (1984, December). IMIS cost/benefit analysis and system trade study. San Diego, CA: Systems Exploration, Inc. (Contract F33615-81-C-0015)

Dengler, D. (1981, December). LCOM II student training guide. AFMSMMET Report 81-2). Wright-Patterson Air Force Base, OH: Air Force Management Engineering Agency.

Department of the Air Force. (1989, October). U. S. Air Force cost and planning factors. (AFR 173-13).

Drake, W., & Wieland, B. (1982, March). LCOM simulation software users reference guide. (AFMSMMET Report 81-1.1). Wright-Patterson Air Force Base, OH: Air Force Management Engineering Agency.

Emerson, D., & Wegner, L. (1985, August). TSAR user's manual -- a program for assessing the effects of conventional and chemical attacks on sortie generation vol. 1, program features, logic, and interaction. (N-2241-AF). Santa Monica, CA: The Rand Corporation.

Garcia, R., & Racher, J. (1981). An investigation into a methodology to incorporate skill level effects into the Logistics Composite Model. (LSSR 29-81, AD A105131). Wright-Patterson Air Force Base, OH: Air Force Institute of Technology.

Gotz, G., & Stanton, R. (1986, January). Modeling the contribution of maintenance manpower to readiness and sustainability. (R-3200-FMP). Santa Monica, CA: The Rand Corporation.

Houston, M. (1960, December). Concepts for estimating Air Force manpower requirements for planning purposes. (RM-2611, AD 250725). Santa Monica, CA: The Rand Corporation.

Houston, M. (1962, February). Manpower planning factors fo . . Force space systems in the conceptual stages of development. (RM-2823-PR). Santa M . . . : The Rand Corporation.

How ell, I (1981, August). Manpower forecasts and planned . . . tenance personnel skill lev l changes. (ASD-TR-81-5018). Wright-Patterson Air Force Ba. ., OH: Aeronautical Systems Division.

Levine, R., & Rainey, R. (1959). The base maintenance operations model used in Rand logistics research. (RM-2374, AD 220605). Santa Monica, CA: The Rand Corporation.

McDonnell Aircraft Company. (1987, October). USAF High Reliability (Hi-Rel) Fighter concept investigation study interim technical report. (Report MDC B0642). St. Louis, MO: McDonnell Aircraft Company.

Nelson, G., Gay, R., & Roll, C. (1974, July). Manpower cost reduction in electronics maintenance. (R-14830-ARPA). Santa Monica, CA: The Rand Corporation.

Nugent, W., Sander, S., Johnson, D., & Smillie, R. (1987, September). Troubleshooting performance using paper and electronic documentation. (NPRDC TN-87-41). San Diego, CA: Navy Personnel Research and Development Center.

Richards, E. (1982, July). Building and operating the Logistics Composite Model for new weapon systems (ASD-TR-82-5033). Wright-Patterson Air Force Base, OH: Aeronautical Systems Division.

Tetmeyer, D (1974, April). Estimating and controlling manpower requirements for new systems: a concept and approach. (AFHRL-TR-74-31, AD A778 838). Wright-Patterson Air Force Base, OH: Advanced Systems Division, Air Force Human Resources Laboratory.

APPENDIX: NOTES ON LCOM

The Logistics Composite Model (LCOM) was created in the late 1960's through a joint effort by The Rand Corporation and the Air Force Logistics Command. The original purpose of LCOM was to provide a policy analysis tool that could relate base-level logistics resources with each other and with sortie generating capability. Logistics resources modeled in LCOM include maintenance people, spare parts, and aerospace ground equipment (AGE). LCOM is an extremely versatile -- and extremely complicated -- model. The interaction of system logistics support factors can be studied in any level of detail the analyst requires. LCOM has been adopted as an Air Force standard, and its most important use has been in determining maintenance manpower requirements.

LCOM software documentation is available (e.g., Drake & Wieland, 1982) and LCOM analyst training guides have been written (e.g., Dengler, 1981). But there is surprisingly little published discussion emphasizing the LCOM manpower determination process itself. LCOM modeling is often seen as a basis for organizing certain kinds of manpower, personnel, and training (MPT) analysis (Boyle, 1990), but very few people have the time or the opportunity to master the intricacies of LCOM. Consequently, a thorough understanding of LCOM has been limited to a small group of LCOM practitioners.

LCOM Simulation Overview

LCOM simulates the work of a maintenance organization. LCOM study objectives may differ widely, but the usual one is to locate the best, or optimal, mix of logistics resources to support a given weapon system under given operating conditions. These logistics resources can be spare parts, support equipment, or human resources (i.e., maintenance people). An LCOM simulation can be used as an experiment in which variations in input resources are related to variations in output. In LCOM, the most important output measure is usually the number of sorties flown. In manpower studies using LCOM, the objective is to find, for each defined work center, the lowest manpower level that just achieves the desired sortie rate. We don't want manpower to be too high, because people would be idle. But we don't want manpower to be too low, because then people would be too busy. We would lose sorties as aircraft wait for maintenance crews to become available. LCOM simulation for manpower amounts to a search for the optimal balance between these two manpower factors and sortie generation potential.

The LCOM model is extremely detailed but it is not difficult to understand the essentials. It is, in many respects, a mere counting device. LCOM logs sorties (and other performance variables) from manpower levels (and other resource information) supplied to it by the analyst. From this perspective, to say that LCOM "determines" manpower is to speak very imprecisely. In fact, the analyst supplies the manpower, LCOM simply counts the sorties corresponding to that manpower level. Through numerous iterations over many simulation runs, the analyst evaluates the sortie/manpower trade-off until an optimal manpower level is found. The manpower level for any Air Force Specialty (AFS) will normally not be lower than the minimum task crew size for the AFS nor higher than that required to satisfy the workload imposed by the flying schedule.

Why Simulation?

The Air Force has favored a simulation approach to aircraft maintenance manpower requirements because mathematical methods, which are based on expected or average long run workload, do not accurately reflect maintenance realities or mission imperatives day by day. The volume of maintenance work fluctuates over time in large part because equipment breaks randomly. Hence, maintenance work cannot be entirely preprogrammed according to some orderly and uniform production rate. Much of the work is "unscheduled" repair of equipment that breaks in a random manner. Though we may be sure that aircraft components will break in the long run, we cannot be certain when they will break in the short run. Hence, to man work centers according to the long run average workload would sometimes mean inadequate sortie production in the short run. A simulation allows random variations in workload demand to reveal themselves and permits manning estimates to take these variations into better account.

The interested reader will find illuminating literature on manpower simulation not just in the current LCOM documentation but particularly in Rand's research in the late 1950's and early 1960's. The work of Houston (1960, 1962) on the "personnel subsystem" concept and Levine & Rainey (1959) on the Base Maintenance Operations Model describe the use of systems analysis tools much like LCOM in manpower planning for new Air Force systems. Newer logistics analysis methods, such as SAMSOM (Bell & Stucker, 1971) and TSAR (Emerson & Wegner, 1985) in the Air Force, and manpower tools such as MANCAP in the Army, attest to the enduring value of the simulation approach to logistics trade-off analysis. See also Gotz & Stanton (1986).

LCOM is called a Monte Carlo simulation because the model uses random draws from equipment failure distributions to introduce demands for unscheduled maintenance work. Similar random draws determine how long a particular repair will take using mean, variance, and distribution types specified by the analyst. In these ways LCOM simulation captures the randomness of real-world events. Simulations must be run repeatedly to determine the "just right" manning level for each work center. Although "variance reduction" and other techniques are often used to make the simulation process more efficient, the LCOM modeling process will usually require more labor and more time than a deterministic mathematical approach to the same modeled environment.

LCOM Model Description

A simplified view of the maintenance world modeled in LCOM is shown in Figure 3. Aircraft are flown, serviced, repaired, and returned to flying status according to rules defined by the modeler. Aircraft process through task networks which describe the procedures and resources of the maintenance environment. In essence, LCOM modeling consists of accumulating statistics on operations and maintenance occurrences in a simulated flying scenario. The level of detail and complexity in the modeled environment can be daunting, but the underlying LCOM process portrayed in Figure 3 is simple.

Maintenance resource levels are set by the analyst, not by LCOM. The model will call upon these resources, human and otherwise, in supplying aircraft to meet the flying demand. Generally speaking, if too few resources are provided, the aircraft will wait and sorties will be lost as maintenance queues develop. If too many resources are provided, they will be underutilized; in effect, wasted. The statistics gathered by the LCOM simulation provide clues about how the resource levels should be changed to improve resource utilization or sortie generation potential in subsequent simulation runs.

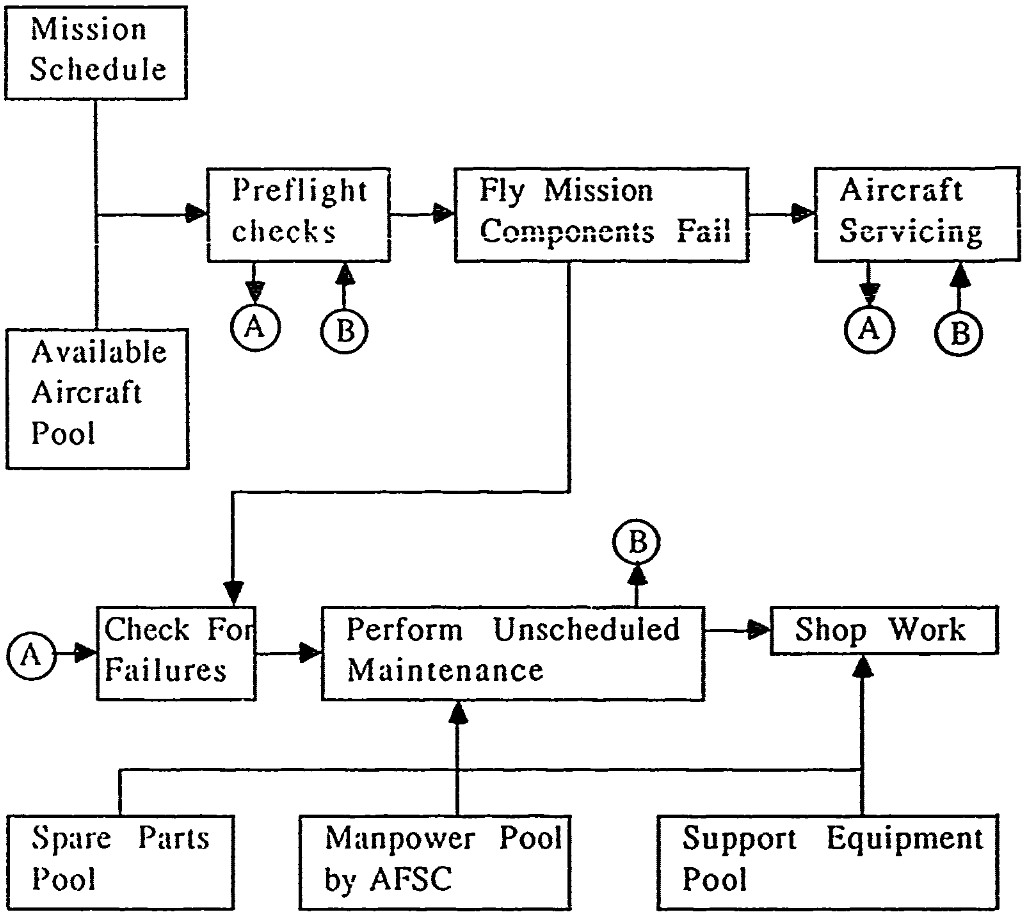

Figure 3. LCOM Simulation Logic. (Adapted from Dengler, 1981)

LCOM Software

The overall structure of the LCOM software, which is written in Simscript II.5, is shown in Figure 4. The LCOM system consists of a preprocessor program (Input Module), a simulation program (Main Module), and Post Processor Modules. The LCOM system also includes a number of supporting programs to aid the data build process. This Data Preparation Subsystem extracts and formats Air Force Maintenance Data Collection System (MDC) data for use in LCOM.

The analyst codes the various LCOM input "forms," which constitute the LCOM data base. After error checking, an LCOM preprocessor converts the data into two files: an initialization ("init", in LCOM jargon) and the exogenous events (or "exog") files. The init file describes the maintenance environment to be simulated and provides staring values for the prescribed variables. The exog file contains flying schedule and related scenario data created from the mission data supplied by the user. This is what creates demand for sorties and maintenance work.

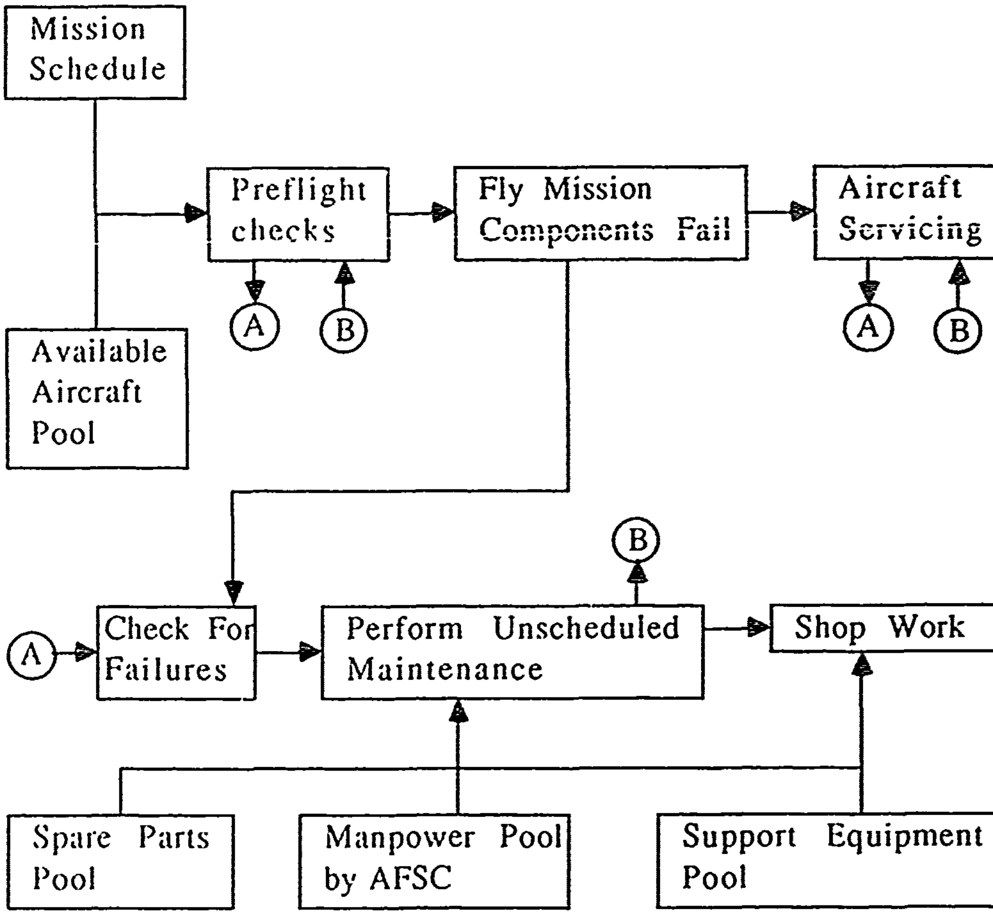

Figure 3. LCOM Simulation Logic. (Adapted from Dengler, 1981)

LCOM Software

The overall structure of the LCOM software, which is written in Simscript II.5, is shown in Figure 4. The LCOM system consists of a preprocessor program (Input Module), a simulation program (Main Module), and Post Processor Modules. The LCOM system also includes a number of supporting programs to aid the data build process. This Data Preparation Subsystem extracts and formats Air Force Maintenance Data Collection System (MDC) data for use in LCOM.

The analyst codes the various LCOM input "forms," which constitute the LCOM data base. After error checking, an LCOM preprocessor converts the data into two files: an initialization ("init", in LCOM jargon) and the exogenous events (or "exog") files. The init file describes the maintenance environment to be simulated and provides staring values for the prescribed variables. The exog file contains flying schedule and related scenario data created from the mission data supplied by the user. This is what creates demand for sorties and maintenance work.

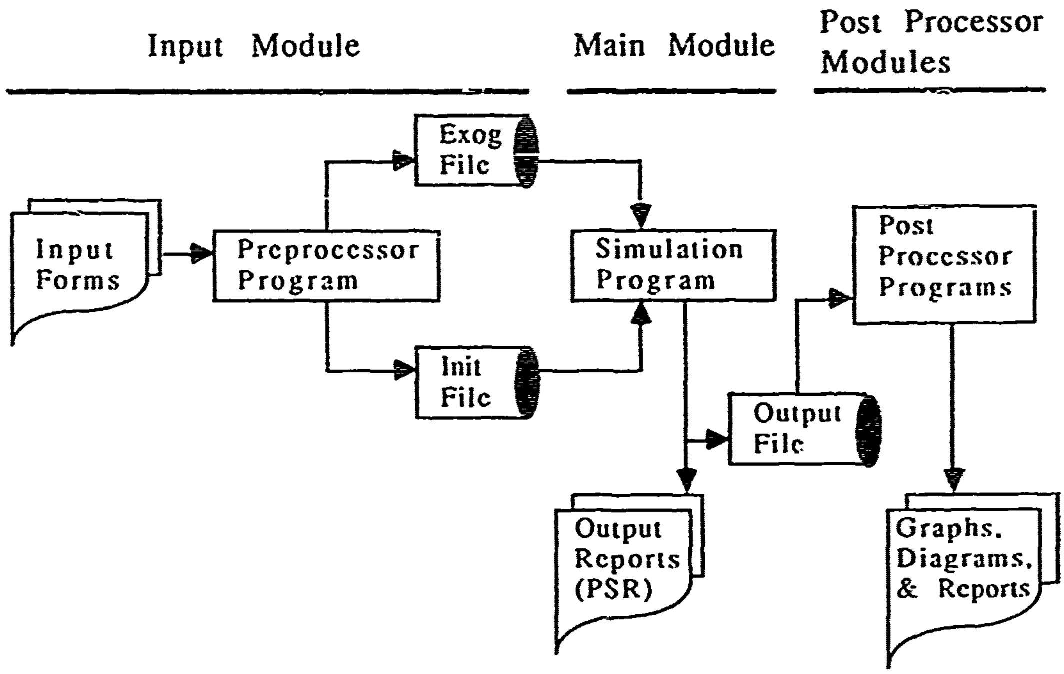

Figure 4. LCOM Software Structure (Adapted from Dengler, 1981)

Dozens of statistics can be produced for the Performance Summary Report (PSR), which is the principal LCOM output. These PSR reports can be ordered at any time during the simulated period The PSR can be likened to a snapshot of maintenance activity. Drake and Wieland (1982) list 79 such statistics in seven categories:[1]

- operations	(e.g., sorties flown)
- activities	(e.g., average time to get resource)
- personnel	(e.g., manhours used, manhours per flying hour)
- supply	(e.g., number of items backordered)
- shop repair	(e.g., number of items repaired)
- AGE	(e.g., aerospace ground equipments used)
- aircraft	(e.g., number of aircraft days available)

[1] The current ASD version of LCOM computes 108 performance statistics.

The Post Processor Modules produce summary statistics for the entire simulated period. These include manpower matrices showing demands for manpower by Air Force Specialty (AFS) by time of day, and usage and availability of spare parts, among others. The matrix and parts reports are particularly important for manpower studies.

The simulated activity consists of maintenance servicing work needed to fuel, arm, and inspect aircraft (main servicing network), and work needed to fix airplanes that have broken in some way (unscheduled maintenance network). The analyst codes this work in a network format identifying, for each task, the time and resources needed to accomplish the work.

The analyst may define so called failure clocks for each aircraft subsytem, component, or part. The failure clocks govern the rate at which things break. This, in turn, governs the volume of unscheduled maintenance manhours. In sum, LCOM cycles aircraft in and out of servicing networks until a failure clock has breached, then it passes aircraft through repair networks, and then returns them to flight status LCOM counts resources used in doing this work. A large array of options have been added to LCOM over the years. These allow the simulated environment to be represented with greater detail, flexibility, and realism. While these options make LCOM look complicated to newcomers, they do not alter the basic logic of the model in any fundamental way.

LCOM Data Base

The LCOM input forms are of fourteen types. The most important of these are listed in Table 6. The data base describes the maintenance environment in terms of resources and tasks and the rules for their use.

Table 6. LCOM Input Forms (P~tial List)

Form Name	Purpose
Task Network	Every task's name, sequence node, selection mode,
Task Definitions	Every task's name, time (mean & variance) and resource ID and quantity (AFS, crew size, spare part, AGE)
Resource Definitions	AFS, spare parts, aircraft, AGE, and failure clocks are identified.
Failure Clock Decrements	Equates equipment failure probabilities to sorties
Shift Change Policy	Defines shift length and how resources are to be allocated to shifts
Mission/Activity Entry Points	Defines when resources enter the network and the required aircraft configuration. Allows tracking and assignment of aircraft to missions.
Priority Specifications	How to handle task conflicts when using resources through preempting, expediting, and restarting rules
Sortie Generation Data	Defines mission types and other scenario data

LCOM Task Language

In LCOM, most maintenance tasks are described as actions taken on a piece of hardware. These tasks require resources (people, parts, and AGE) and time. The actions ›pplicable to people are:

On-equipment (flightline)	Off-equipment (shop)
X = Access (Use AGE)	L = Component identification
T = Troubleshoot	W = Check/repair component
R = Remove and replace	K = Component checks OK
H = Inspect	N = Check and condemn
M = Repair	Y = Disassemble/reassemble

V = Verify system works
J = Aircraft handling
B = Loading/downloading munitions
W = Check/repair component (shop)

When these action codes are paired with equipment Work Unit Codes, a concise task descriptive language is created. For example, "T74AB0" in LCOM means "troubleshoot the (F-16) radar low power RF." The entire LCOM language for unscheduled maintenance is used in this "action taken/work unit code" manner. For generic aircraft servicing work and work that cannot be tied precisely to to specific equipments, words like FUEL, LAUNCH, and TOW are also used.

The task descriptive vocabulary used by LCOM is exact but it is also rather limited. There is no implication in LCOM maintenance networks of what military psychologists would call task analysis That is, the only things LCOM knows about a task is who does it, how many are needed, who may substitute, what support equipment is needed, and how long the task takes. Through the failure clocks, LCOM also knows how often a task is apt to occur. LCOM knows nothing else about the qualitative aspects of the work. LCOM task data bases contain only the task information relevant to manpower utilization. LCOM can be used to model manpower and/or sortie impacts of different skill level mixes (Howell, 1980; Garcia & Racher, 1981). And LCOM task data have also been used for manpower, personnel, and training task analysis for AFS redefinition (Boyle, 1990) But excursions such as these depend on task information that is developed outside the standard LCOM process.

LCOM Task Networks

LCOM tasks are placed into networks that define their logical flow and resource requirements. These networks can be defined in many different ways and in any level of detail desired. The task in Figure 5, for example, begins when a failure clock for Part X has "breached." The network section applicable to Part X is activated. The aircraft will halt processing through the main servicing network while maintenance is performed.

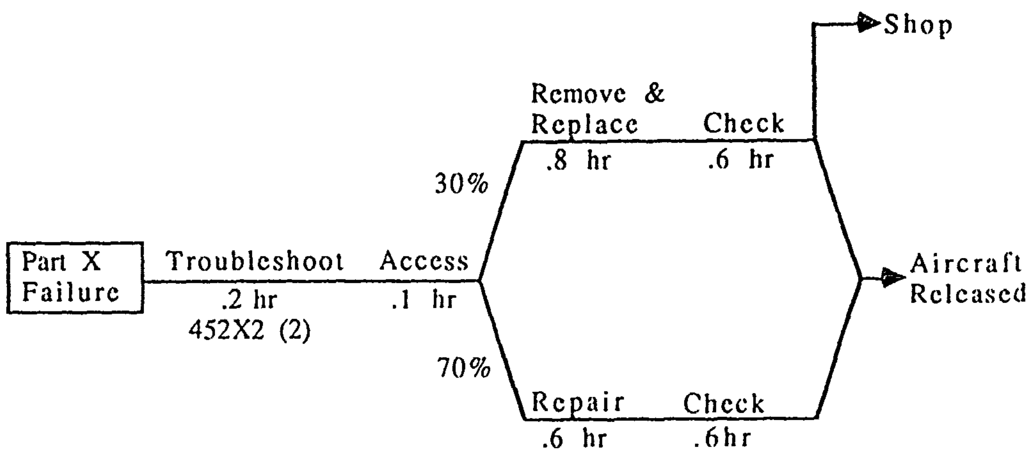

Figure 5. LCOM Network Example.

The diagram shows that it takes a crew of two people with AFS 452X2 three tenths of an hour to identify the problem. A repair action taking .6 hours will result 70 percent of the time, a remove & replace action taking .8 hours 30 percent of the time. After a check, the aircraft continues processing. Use of AFS 452X2 is recorded as 3.4 manhours in the remove & replace action, and 3.0 manhours in the repair action. Shop manhours are also generated when the failed part arrives for repair. The frequency with which this network section is activated is governed by Part X's failure clock and its expected reliability. The manhours consumed by this task network are summed over the entire simulation period. When the LCOM study is complete, these manhours are converted into a manpower requirement.

LCOM provides a wide array of task networking controls. These can be used, for example, to:

- "call" other tasks or networks,
- create probabilistic branching (Figure A-3)
- skip over or accomplish tasks in parts
- define sequential and parallel task strings
- consume and generate parts
- change the location of resources
- and decrement failure clocks

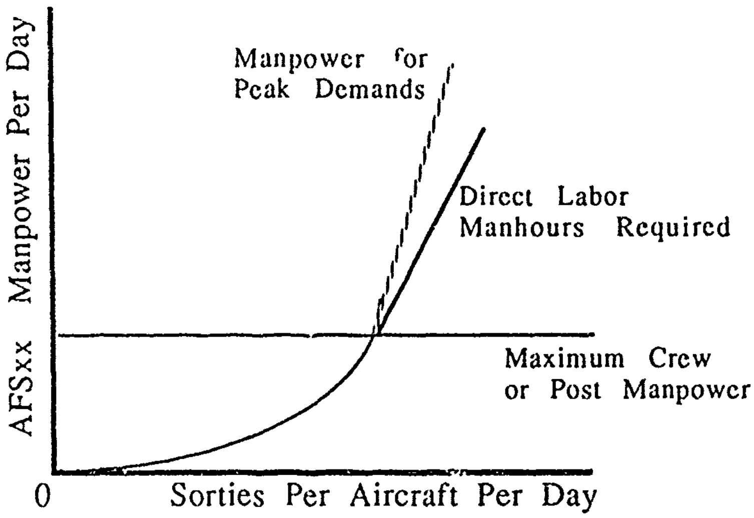

Figure 6. Manpower Factors. (Adapted from Dengler, 1981)

The relationship of manpower factors to sortie rate is shown in Figure 6. During manpower constraining, the LCOM analyst must consider which of these factors is driving the manpower requirement. Other things equal, the sortie rate will govern the manpower factors. The manpower factors are:

Post Manpower: Crews dedicated to a fixed post (e.g., end-of-runway checks) for a fixed period and who cannot be reassigned during the work shift.

Crew Size: Manpower on at least one shift must be at least equal to the highest crew size for any single task for that AFS. Each task in LCOM has a defined crew size. Most maintenance tasks require more than one person. A charming LCOM locution names the highest crew size in any AFS's task inventory the "maximum minimum crew size." Normally, manpower cannot be lower than this regardless of workload.

Direct Labor: The manpower level needed to accomplish the direct work hours generated by the simulation. It is shown in Figure 6 as a near linear increasing function of sorties flown.

Peak Demand: Sortie demand may have an irregular pattern through the day. Massed fights or surge conditions may require many people to be working at the same time. More people may be needed to cover these peak demands than might be provided through using the other manning factors alone. Additional manpower might will have to be provided to satisfy these surges in sortie demand.

Manpower Constraining

When spare parts constraining is done, manpower constraining begins. The required manning levels for each work center (or AFS) are determined through a progressive and systematic process of constraining over many simulation runs. This process calls upon LCOM statistical reports as well as the analyst's judgment.

Dengler (1981) describes the following method. In the equation,

$$M(s) = \frac{\text{AFS Manhours Used}}{(\text{Utilization Factor})\times(\text{Number of Days})\times(\text{Shift Length})}$$

manhours used by each AFS are converted to average daily number of people required for a shift [M(s)] by taking shift length, days simulated, and manpower utilization or availability factors into account. The latter factors, by current Air Force policy, are 144.5 hours per person per month (peacetime) and 244.8 hours per person per month (wartime). The analyst must decide which policy is applicable to his simulation problem. The shift manning levels so derived become starting values for manpower constraining runs. The analyst must be careful in allocating people to shifts. AFS manning should not be lower than the maximum minimum crew size if no AFS substitution rules have been defined. LCOM simulations are performed using so-called change cards which list "authorized" resource levels.

The analyst is guided in setting manning levels for subsequent LCOM runs by monitoring the sortie rate and manpower utilization statistics associated with a given manning level. AFSs that may need additional manpower can often be identified by examining the Manpower Matrix Post Processor, which shows AFS "backorder" statistics. The analyst must determine whether repair delays in particular work centers are constraining the sortie rate. These delays might be tolerated if they do not constrain the sortie rate.

Finally, the actual manpower is derived. After the analyst has completed all AFS manning adjustments and is satisfied that LCOM has confirmed the optimal manpower levels for each AFS, he has one final calculation to make. The number of authorizations (i.e., the number of whole people to be listed on unit manning documents) for each AFS depends on the total daily LCOM requirement for all shifts, the monthly manpower availability factor, the work days per month, and the shift length. The equation below shows how this calculation is made.

$$M = \frac{\text{Average Daily LCOM Derived Manpower} \times \text{Work Days Per Month} \times \text{Shift Length}}{\text{Manpower Availability Factor}}$$

The term "whole people" above is used advisedly. Division with fractional availability factors will give rise to fractional manpower requirements. Since we can deal with real people only in whole (integer) units, tables for rounding these fractions into whole-person equivalents are used.